

Large Dimuon Asymmetry In $B_s - \bar{B}_s$ Mixing From Unparticle Induced Γ_s^{12}

Bo Ren¹, Xiao-Gang He^{1,2}, Pei-Chu Xie¹

¹*INPAC, Department of Physics,
Shanghai Jiao Tong University,
Shanghai, China*

²*Department of Physics and Center for Theoretical Sciences,
National Taiwan University, Taipei, Taiwan*

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Abstract

Exchange of unparticle stuff of dimension d_U with FCNC interaction can induce $M^{12,u}$ and $\Gamma^{12,u}$ causing meson and anti-meson mixing with the relation $\Gamma^{12,u}/M^{12,u} = 2 \tan(\pi d_U)$. We show that this type of unparticle contribution can provide the much needed large Γ_s^{12} to explain the recently observed anomalously large dimuon asymmetry in $B_s - \bar{B}_s$ system reported by D0 collaboration. The same interaction can also accommodate large mixing induced CP violation in $B_s \rightarrow J/\psi\phi$ indicated by CDF and D0 data. Experimental data can provide constraints on the unparticle dimension and scale.

Recently the D0 Collaboration has reported evidence for an anomalously large CP violation in the like-sign dimuon charge asymmetry [1] which is attributed to semileptonic decays of b hadrons defined by

$$A_{\text{sl}}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}, \quad (1)$$

where N_b^{++} (N_b^{--}) is the number of events with two b hadrons ($b\bar{b}$) decaying semileptonically into $\mu^+\mu^+X$ ($\mu^-\mu^-X$). The D0 result [1], $A_{\text{sl}}^b = -(9.57 \pm 2.51 \pm 1.46) \times 10^{-3}$ with the first and the second errors being statistical and systematic ones, is 3.2σ away from the standard model (SM) prediction of -0.2×10^{-3} [2].

A_{sl}^b is related to the “wrong-charge” asymmetries $a_{\text{sl}}^{d,s}$ in B_d and B_s decays

$$a_{\text{sl}}^q \equiv \frac{\Gamma(\bar{B}_q \rightarrow \mu^+ X) - \Gamma(B_q \rightarrow \mu^- X)}{\Gamma(\bar{B}_q \rightarrow \mu^+ X) + \Gamma(B_q \rightarrow \mu^- X)}. \quad (2)$$

With known values for mixing parameters of B_d and B_s systems, one obtains [1, 3]

$$A_{\text{sl}}^b = (0.506 \pm 0.043)a_{\text{sl}}^d + (0.494 \pm 0.043)a_{\text{sl}}^s. \quad (3)$$

The above leads to [1] $a_{\text{sl}}^s = -0.0146 \pm 0.0075$, after insert the known value [1, 4] $a_{\text{sl}}^d = -0.0047 \pm 0.0046$. Combining direct information on a_{sl}^s from CDF [5] and D0 [6], one can extract an average value of

$$(a_{\text{sl}}^s)_{\text{ave}} \approx -(12.7 \pm 5.0) \times 10^{-3}. \quad (4)$$

The “wrong-charge” asymmetry for $B_s - \bar{B}_s$ mixing is determined by the matrix elements M_s^{12} and Γ_s^{12} in the Hamiltonian,

$$a_{\text{sl}}^s = -\frac{\text{Im}(M_s^{12}\Gamma_s^{12*})}{|M_s^{12}|^2 + |\Gamma_s^{12}|^2/4} \approx -\frac{|\Gamma_s^{12}|}{|M_s^{12}|} \sin \phi_s. \quad (5)$$

In the above, for the last step of approximation, we have neglected small corrections of order $|\Gamma_s^{12}|^2/|M_s^{12}|^2$.

The SM prediction of $|\Gamma_s^{12,SM}|/|M_s^{12,SM}|$ is $(4.97 \pm 0.94) \times 10^{-3}$ and the phase ϕ_s is small leading to a value $(2.1 \pm 0.6) \times 10^{-5}$ for a_{sl}^s [2]. This is 2.5σ away from $(a_{\text{sl}}^s)_{\text{ave}}$, and the predicted central value is more than two orders of magnitude smaller. If the D0 result is confirmed, it is an indication of new physics beyond the SM. Implications of this result have been studied recently by several groups [7–33].

Different values of M_s^{12} and Γ_s^{12} than those predicted by SM are needed. In many models beyond the SM, there are new FCNC interactions which can easily induce large modification to M_s^{12} , but not to Γ_s^{12} , such as Z' and SUSY models. If modifications to Γ_s^{12} is negligible, i.e. $\Gamma_s^{12} = \Gamma_s^{12,SM}$, one can write [1, 2]

$$a_{sl}^s = -\frac{|\Gamma_s^{12,SM}|}{|M_s^{12,SM}|} \frac{\sin \phi_s}{|\Delta_s|} = -(4.97 \pm 0.94) \times 10^{-3} \frac{\sin \phi_s}{|\Delta_s|} . \quad (6)$$

with

$$M_s^{12} = M_s^{12,SM} + M_s^{12,NP} = M_s^{12,SM} \Delta_s = |M_s^{12,SM}| |\Delta_s| e^{i\phi_s} . \quad (7)$$

In the above, $M_s^{12,NP}$ indicates the contribution from beyond the SM new physics. We have neglected small SM contribution to ϕ_s and adopted the phase convention that Γ_s^{12} is real.

Since the SM contribution to the phase ϕ_s is small, it is convenient to write the expression explicitly in terms of the new physics contribution defined by $M_s^{12,NP}/|M_s^{12,SM}| = R \exp(-i\phi^{NP})$, one then has [17]

$$a_{sl}^s = \frac{|\Gamma_s^{12,SM}|}{|M_s^{12,SM}|} \frac{R \sin \phi^{NP}}{1 + 2R \cos \phi^{NP} + R^2} ,$$

$$|\Delta_s| = \sqrt{1 + 2R \cos \phi^{NP} + R^2} . \quad (8)$$

The SM prediction for $\Delta M_s \approx 2|M_s^{12}|$ agrees with data well, $|\Delta_s|$ is only allowed to vary in a limited region, 0.92 ± 0.32 fixed by the experimental value [3] $\Delta M_s = (17.77 \pm 0.12) ps^{-1}$ and the SM prediction [2] $(19.30 \pm 6.74) ps^{-1}$. In order to reproduce the D0 result, naively it seems that $\sin \phi_s$ would have to exceed the physical range $|\sin \phi_s| < 1$ to reach the central value from data. A large beyond SM new physics contribution $\Gamma_s^{12,NP}$ to Γ_s^{12} is therefore called for. Several attempts have been made in this direction [9, 16, 17, 30].

In this work we show that unparticle FCNC interaction can provide the much needed large $\Gamma_s^{12,u}$ to explain the observed anomalously large dimuon asymmetry in $B_s - \bar{B}_s$ system by D0 collaboration. Using experimental data, one can constrain the dimension $d_{\mathcal{U}}$ and the unparticle scale.

Several years ago Georgi proposed an interesting idea to describe possible scale invariant effect at low energies by unparticles [34]. An unparticle operator $O_{\mathcal{U}}$ of dimension $d_{\mathcal{U}}$ resulting from some scale invariant theory at high energy may interact with SM particles at low energy in the following form

$$\lambda \Lambda_{\mathcal{U}}^{4-d_{SM}-d_{\mathcal{U}}} O_{SM} O_{\mathcal{U}} . \quad (9)$$

where O_{SM} is composed of SM fields.

If the O_{SM} is a bi-quark operator with different quarks, exchange of unparticle stuff can induce meson and antimeson mixing [35]. Unlike usual tree level contributions to meson oscillations from heavy particle exchange which produces a small Γ^{12} , the unparticle may have sizeable contributions to both $M^{12,u}$ and $\Gamma^{12,u}$ due to unparticle fractional dimension d_U leading to a phase factor [34, 36] $(-1)^{d_U-2} = e^{-i\pi d_U}$ in the propagator which is proportional to $M^{12} - i\Gamma^{12}/2$. This leads to an interesting relation $\Gamma^{12,u}/M^{12,u} = 2 \tan(\pi d_U)$. Depending on the dimension d_U , $\Gamma^{12,u}$ can even be larger than $M^{12,u}$.

Contributions to $M^{12,u}$ and $\Gamma^{12,u}$ for a class of operators O_{SM} with dimension less than or equal to 4 interacting with unparticles, respecting SM symmetries [37], have been studied in Ref. [38]. Here we take a scalar unparticle O_U interaction with quarks, respecting SM gauge symmetry, of the following forms for illustration,

$$i\tilde{\lambda}_{ij}^D \Lambda_U^{-d_U} \bar{d}_R^i \gamma_\mu d_R^j \partial^\mu O_U, \quad i\tilde{\lambda}_{ij}^Q \Lambda_U^{-d_U} \bar{Q}_L^i \gamma_\mu Q_L^j \partial^\mu O_U, \quad (10)$$

where d_R^i and $Q_L^{iT} = (u_L^i, d_L^i)$ are the right-handed down-quarks and left-handed quarks, respectively.

After using equation of motion for quarks, one can write the above tree level FCNC interaction as

$$\mathcal{L} = \Lambda_U^{1-d_U} \frac{m_j}{\Lambda_U} \bar{d}_i [\tilde{\lambda}_{ij}^D (\frac{m_i}{m_j} R - L) + \tilde{\lambda}_{ij}^Q (\frac{m_i}{m_j} L - R)] d_j O_U. \quad (11)$$

Let j be the heavier and i be the lighter quarks, the term proportional to m_i/m_j can be neglected.

Note that the above Lagrangian, in general, can induce $B_s \rightarrow O_U$ transition making a large contribution to B_s invisible decay rate for $i = s$ and $j = b$. If there is no similar interaction for $i = d$, this will also induce a significant lifetime difference between B_d and B_s . These problems can be solved if the couplings $\tilde{\lambda}_{sb}^D$ and $\tilde{\lambda}_{sb}^Q$ are equal, $\tilde{\lambda}_{sb}^D = \tilde{\lambda}_{sb}^Q$, such that the above Lagrangian is proportional to $\bar{s}b O_U$ which cannot induce $B_s \rightarrow O_U$ transition. We will work with this condition.

Exchange of unparticle in the t and s channels as shown in Fig. 1, we obtain the effective Hamiltonian H_{eff}^U responsible for meson-antimeson mixing

$$H_{eff}^U = \frac{A_{d_U}}{2 \sin(\pi d_U)} \Lambda_U^{2(1-d_U)} \frac{m_j^2}{\Lambda_U^2} e^{-i\pi d_U} \frac{1}{4} \left(\frac{1}{(s - \mu^2)^{2-d_U}} + \frac{1}{(t - \mu^2)^{2-d_U}} \right) \left(\bar{d}_i [\tilde{\lambda}_{ij}^D L + \tilde{\lambda}_{ij}^Q R] d_j \right)^2 \quad (12)$$

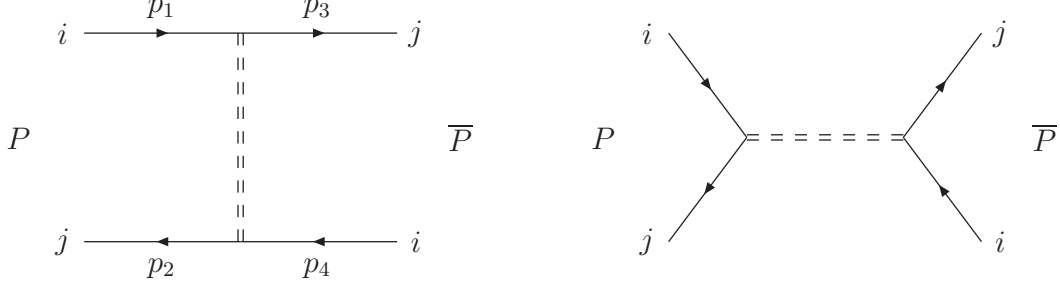


FIG. 1: The t and s channel contributions to meson-antimeson oscillation.

Here $A_{d_{\mathcal{U}}} = (16\pi^{5/2}/(2\pi)^{2d_{\mathcal{U}}})\Gamma(d_{\mathcal{U}} + 1/2)/(\Gamma(d_{\mathcal{U}} - 1)\Gamma(2d_{\mathcal{U}}))$. We have used $(iA_{d_{\mathcal{U}}}/2\sin(\pi d_{\mathcal{U}}))e^{-id_{\mathcal{U}}\pi}(1/(p^2 - \mu^2)^{2-d_{\mathcal{U}}})$ for the scalar unparticle propagator [39]. One can easily identify the factor $e^{-i\pi d_{\mathcal{U}}}$ in the propagator producing a non-zero $\Gamma^{12,u}$ mentioned earlier.

In the above we have followed Ref. [39] to use a modified unparticle propagator to take into account the breaking of conformal invariance at a scale μ lower than $\Lambda_{\mathcal{U}}$ by unparticle interaction with SM particles. When p^2 becomes smaller than μ^2 , the unparticle contribution to Γ_{12} vanishes. The scale μ is not known, since we rely on the unparticle effect to generate Γ_s^{12} , we will allow it to be lower than B_s mass. One should not allow μ to be too small to allow $b \rightarrow sO_{\mathcal{U}}$ process to happen which will contribute too large an invisible decay rate for $b \rightarrow sO_{\mathcal{U}}$ which changes B_s lifetime dramatically. For this reason we assume that μ is in the range of $m_{B_s} > \mu > m_{B_s} - m_K$ such that $b \rightarrow sO_{\mathcal{U}}$ is forbidden.

In $B_s - \bar{B}_s$ system, mesons are made of a $i = s$ light quark and a $j = b$ heavy. In the heavy quark limit, one has $s = t \approx m_b^2 \approx m_{B_s}^2$. With this approximation and theoretical matrix elements for the relevant operators, we have

$$M_s^{12,u} - i\frac{1}{2}\Gamma_s^{12,u} \approx \frac{A_{d_{\mathcal{U}}}}{\sin(d_{\mathcal{U}}\pi)} \left(\frac{m_{B_s}^2 - \mu^2}{\Lambda_{\mathcal{U}}^2} \right)^{d_{\mathcal{U}}-2} \left(\frac{m_{B_s}^2}{\Lambda_{\mathcal{U}}^2} \right)^2 \frac{f_{B_s}^2}{12m_{B_s}} B_{B_s} \frac{e^{-i\pi d_{\mathcal{U}}}}{8} \\ \times \left((\tilde{\lambda}_{sb}^D)^2 + (\tilde{\lambda}_{sb}^Q)^2 - 6((\tilde{\lambda}_{sb}^D)^2 - (\tilde{\lambda}_{sb}^Q)^2) + 2\tilde{\lambda}_{sb}^D \tilde{\lambda}_{sb}^Q \right), \quad (13)$$

where B_{B_s} is the bag factor which is equal to 1 in the vacuum saturation and factorization approximation. With the condition $\tilde{\lambda}_{sb}^D = \tilde{\lambda}_{sb}^Q$, the factor in the second line of the above equation becomes $4(\tilde{\lambda}_{sb}^Q)^2$.

It is clear from Eq. (13) that because of the phase factor $e^{-i\pi d_{\mathcal{U}}}$ in the propagator, there

is a relation between $M_s^{12,u}$ and $\Gamma_s^{12,u}$ that

$$\frac{\Gamma_s^{12,u}}{M_s^{12,u}} = 2 \tan(\pi d_{\mathcal{U}}). \quad (14)$$

There may be a sizeable contribution to $\Gamma_s^{12,u}$ at tree level which is not possible for usual tree level heavy particle exchange. For $d_{\mathcal{U}}$ equal to half integers, there is no contribution to $M_s^{12,u}$, but there is for $\Gamma_s^{12,s}$. It has been shown [38] that a large class of unparticle tree level interaction contributions to meson and antimeson mixing can be written in the form of Eq. (15).

One can group unknown parameters in such a way that

$$M_s^{12,u} = |M_s^{12,u}| e^{-i\phi_{\mathcal{U}}} , \quad \Gamma_s^{12,u} = 2 |M_s^{12,u}| e^{-i\phi_{\mathcal{U}}} \tan(\pi d_{\mathcal{U}}) , \quad (15)$$

where

$$|M_s^{12,u}| e^{-i\phi_{\mathcal{U}}} = |A_{d_{\mathcal{U}}} \left(\frac{m_{B_s}^2}{\tilde{\Lambda}_{\mathcal{U}}^2} \right)^{d_{\mathcal{U}}} \frac{f_{B_s}^2}{24 m_{B_s}} B_{B_s} \cot(d_{\mathcal{U}} \pi) | e^{-i\phi_{\mathcal{U}}} . \quad (16)$$

Here we have identified the phase of $\tilde{\lambda}_{sb}^Q$ to be $-\phi_{\mathcal{U}}/2$ and defined the reduced unparticle scale $\tilde{\Lambda}_{\mathcal{U}} = \Lambda_{\mathcal{U}} (1 - \mu^2/m_{B_s}^2)^{1/d_{\mathcal{U}}-1/2} |\tilde{\lambda}_{sb}^Q|^{-1/d_{\mathcal{U}}}$. $\tilde{\Lambda}_{\mathcal{U}}$ is an effective indicator of the scale of unparticle physics. This quantity actually contains three unknown quantities, $\Lambda_{\mathcal{U}}$, $|\lambda_{sb}^Q|$ and μ . Since we do not have good ideas about their individual sizes, we will use the reduced scale for discussions later. In general $\tilde{\lambda}_{sb}^Q$ is complex, therefore $\phi_{\mathcal{U}}$ can take an arbitrary value between 0 to 2π .

Combining the SM contribution and neglect small phase there, we have

$$a_{\text{sl}}^s = \frac{|\Gamma_s^{12,SM}|}{|M_s^{12,SM}|} \frac{R \sin(\phi_{\mathcal{U}})}{1 + 2R \cos(\phi_{\mathcal{U}}) + R^2} - \frac{2 \tan(d_{\mathcal{U}} \pi) R \sin(\phi_{\mathcal{U}})}{1 + 2R \cos(\phi_{\mathcal{U}}) + R^2} , \quad (17)$$

$$|\Delta_s| = \sqrt{1 + 2R \cos(\phi_{\mathcal{U}}) + R^2} .$$

The first term in the expression for a_{sl}^s is similar to the contribution without modification to Γ_s^{12} analyzed in Ref. [17]. The second term is new which comes from unparticle modification to Γ_s^{12} .

There are two constraints with three parameters, R , $\phi_{\mathcal{U}}$ and $y = \tan(d_{\mathcal{U}} \pi)$. It is not possible to determine all the theoretical parameters. However, one can express two of the theoretical parameters as a function of the experimental measurable quantities and another

theoretical parameter. We find

$$\begin{aligned}\cos(\phi_{\mathcal{U}}) &= \frac{|\Delta_s|^2 - 1 - R^2}{2R}, \\ y &= \frac{1}{2} \left(\frac{|\Gamma_s^{12,SM}|}{|M_s^{12,SM}|} \pm \frac{2a_{sl}^s R |\Delta_s|^2}{\sqrt{4R^2 - (|\Delta_s|^2 - 1 - R^2)^2}} \right).\end{aligned}\quad (18)$$

The “ \pm ” sign in the expression for y comes from the need of taking a square root for $\sin(\phi_{\mathcal{U}})$ from knowing $\cos(\phi_{\mathcal{U}})$.

Since the physical range of $\cos(\phi_{\mathcal{U}})$ is limited to be from -1 to 1, from the first equation about, one can obtain a constrain for the allowed ranges for R . We show this in Fig. 2 for several values of $|\Delta_s|$. In the plot we have used the central values for the relevant SM quantities.

With the allowed range for R known, for given a_{sl}^s and $|\Delta_s|$, y can be determined as a function of R . For example, with central values for a_{sl}^s and $|\Delta_s|$, for $R = 0.5, 1.0, 1.5$, we have $y = 0.008, 0.009, 0.012$ and $y = -0.003, -0.004, -0.007$ with “-” and “+” signs in eq. 18, respectively. a_{sl}^s and $|\Delta_s|$ can be accommodated with reasonable values for other parameters. y can take both positive or negative signs. To have further information on $d_{\mathcal{U}}$, one should also consider $d_{\mathcal{U}} = n + (\arctan y)/\pi$ with n an arbitrary integer. However, if one considers the relation between the reduced scale $\tilde{\Lambda}_{\mathcal{U}}$ and $d_{\mathcal{U}}$, one would prefer not too large a $d_{\mathcal{U}}$. If one limits $d_{\mathcal{U}}$ between 1 and 2, when y takes a positive value, one should take $n = 1$. When y is negative, it is reasonable to take $n = 2$.

The unparticle interaction we have introduced can also have effects on other flavor changing processes which may exclude some of the parameter space favored by producing the a_{sl}^s value obtained by D0. For $\Delta S = 1$ processes, such as $B_{s,d}$ decays with SM final states and unparticle as intermediate state, there is the need to introduce new unparticle interaction with other SM particles, one can adjust the new couplings to be sufficiently small to satisfy bounds from experimental data. This type of interaction will not affect the analysis carried out earlier and we will not discuss them further. There are, however, experimental observables which depend on the quantities we have discussed. For example mixing induced CP violation in B_s decays can be affected by modifications to M_s^{12} , in particular, experimental data on mixing induced CP violation in $B_s \rightarrow J/\psi\phi$ can further constraint the interaction discussed.

Recently analysis from CDF and D0 data show that there are indications of mixing

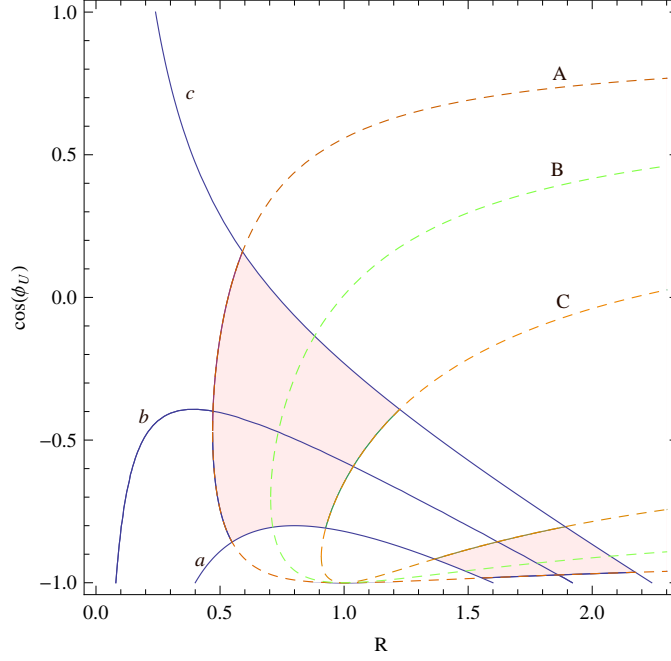


FIG. 2: R vs. $\cos(\phi_U)$. The solid and dashed curves are for $|\Delta_s|$ and $\sin \phi_s$ taking their central and one σ upper and lower values, respectively. The shaded areas are the one σ overlap regions. ($|\Delta_s| = 0.6$ (a), $|\Delta_s| = 0.92$ (b), $|\Delta_s| = 1.24$ (c); $\sin \phi_s = -0.470$ (A), $\sin \phi_s = -0.704$ (B)), $\sin \phi_s = -0.908$ (C)).

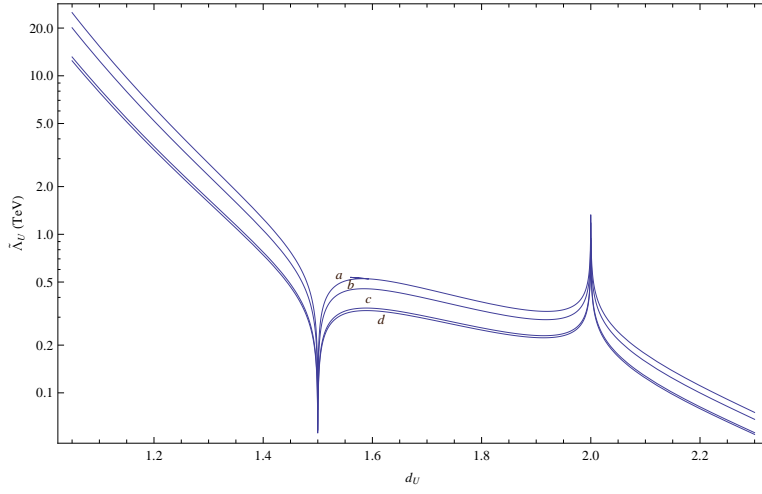


FIG. 3: $\tilde{\lambda}_U$ vs. d_U for fixed $R = 0.46; 0.73; 1.78; 2.00$, in order from up to down (magenta (a); green (b); blue (c); red (d)), respectively.

induced CP violation in $B_s \rightarrow J/\psi \phi$ decay with [40]

$$\beta_s^{J/\psi \phi} = (0.39^{+0.18}_{-0.14}) \cup (1.18^{+0.14}_{-0.18}), \quad (19)$$

where the second set in the last line is just the complement of $\pi/2$. This reflects the ambiguity in the determination of $\beta_s^{J/\psi\phi}$.

If there is no new interaction in the decay amplitude, $-2\beta_s^{J/\psi\phi}$ is the phase of M_s^{12} . The SM prediction for $\beta_s^{J/\psi\phi}$ is given by [2], $\beta_s^{J/\psi\phi(SM)} = \text{Arg}(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}) \approx 0.019 \pm 0.001$. The central value of $\beta_s^{J/\psi\phi(SM)}$ is much smaller than that from CDF and D0 and can be neglected. If confirmed, this also requires new physics beyond SM. Even though we do not introduce new unparticle interactions in the decay amplitude, M_s^{12} is modified which can affect mixing induced CP violation in $B_s \rightarrow J/\psi\phi$. We have $-2\beta_s^{J/\psi\phi} \approx \phi_s$. Here ϕ_s is defined in Eq. (7). The two values for $\beta_s^{J/\psi\phi}$ give approximately the same $\sin(\phi_s)$ with the central values given by -0.704 and the one σ range of $-0.908 \sim -0.470$.

Translating into R and ϕ_U defined earlier, we have

$$\sin \phi_s = \frac{-R \sin(\phi_U)}{\sqrt{1 + 2R \cos(\phi_U) + R^2}}. \quad (20)$$

It is clear that a non-zero ϕ_U can modify the SM prediction for $\beta_s^{J/\psi\phi}$.

Using the above one can further constraint the allowed regions for R and $\cos(\phi_U)$. From the relation between ϕ_s and ϕ_U , one finds $\sin(\phi_U)$ must be positive. The allowed regions for $\cos(\phi_U)$ are shown in Fig. 2. The shaded regions are the one σ allowed common regions.

With three unknowns and three input experimental data points, we can completely express R , $\cos(\phi_U)$ and y as functions of $|\Delta_s|$, ϕ_s and a_{sl}^s . We have

$$\begin{aligned} R &= \sqrt{1 \pm 2|\Delta_s| \cos \phi_s + |\Delta_s|^2}, \\ \cos(\phi_U) &= \frac{-1 \mp |\Delta_s| \cos \phi_s}{\sqrt{1 \pm 2|\Delta_s| \cos \phi_s + |\Delta_s|^2}}, \\ y &= \frac{1}{2} \left(\frac{|\Gamma_s^{12,SM}|}{|M_s^{12,SM}|} + \frac{a_{sl}^s |\Delta_s|}{\sin \phi_s} \right). \end{aligned} \quad (21)$$

We now use the above equations to determine central values and their one σ errors for R , $\cos(\phi_U)$ and y . Since the error correlations between the three experimental observable quantities are not know, a complete analysis is not possible. To have some idea about the ranges for the theoretical parameters, we will assume that they are independent quantities satisfying Gaussian distribution and take the average one σ lower and upper bounds as their one σ errors for illustration. The results are listed in Table 1. For a given set of input data, there are two solutions for R and $\cos(\phi_U)$, but the solution for y is single valued. We see

R	$\cos(\phi_{\mathcal{U}})$	y
1.776 ± 0.185	-0.931 ± 0.055	0.011 ± 0.004
0.735 ± 0.276	-0.472 ± 0.208	

TABLE I: The central values and one σ bounds of R , $\cos(\phi_{\mathcal{U}})$ and y .

that y is restricted to be positive now. The large dimuon asymmetry in $B_s - \bar{B}_s$ mixing and large mixing induced CP violation in $B_s \rightarrow J/\psi\phi$ can be simultaneously explained.

Finally, we briefly comment on the implications of constraints on the effective unparticle scale $\tilde{\Lambda}_{\mathcal{U}}$. Using the results obtained on R , we can work backward to obtain information about the reduced unparticle scale, $\tilde{\Lambda}_{\mathcal{U}}$. For a given R , $\tilde{\Lambda}_{\mathcal{U}}$ can be expressed as a function of $d_{\mathcal{U}}$. We show the results in Fig. 3. In plotting Fig. 3, we have used $B_{B_s} = 1$ and $f_{B_s} = 0.260$ GeV [41]. We can see, as expected for larger $d_{\mathcal{U}}$, a lower scale is needed which may have already reached by current colliders. Since no evidence of unparticle effects have shown up explicitly, one should set a lower limit for that. For a lower bound of $\tilde{\Lambda}_{\mathcal{U}}$ larger than 1 TeV, we see that $d_{\mathcal{U}}$ is restricted to be lower than 1.5.

In summary we have shown that unparticle induced contribution to $B_s - \bar{B}_s$ mixing can provide the much needed large Γ_s^{12} to explain the recently observed anomalously large dimuon asymmetry by D0 collaboration. The same interaction can also accommodate large mixing induced CP violation in $B_s \rightarrow J/\psi\phi$ from CDF and D0 data. Experimental data also provide constraints on unparticle dimension and scale parameters.

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Note Added

While we are in the final stage of finishing our work, a paper [42] by J. P. Lee appeared where unparticle effects on $B_s - \bar{B}_s$ was also discussed in the context of large dimuon asymmetry reported by D0. We do not agree Lee's interpretation for the part proportional to $\sin(\pi d_{\mathcal{U}})$ generated due to the $e^{-i\pi d_{\mathcal{U}}}$ factor in the propagator. It contributes to Γ_s^{12} , but not M_s^{12} . Our emphasis is on how the unparticle effects modification for Γ_s^{12} plays a crucial role in explaining the data reported by D0. In general a CP violating phase, in our notation $\phi_{\mathcal{U}}$, can also exist. This phase is not considered in the analysis by Lee.

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